REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
15-03-2004	Final Report	14 February 2001 - 14-Feb-03

4. TITLE AND SUBTITLE

Acceleration Tolerance Improvement With Full-Coverage Anti-G Suits

5a. CONTRACT NUMBER
F61775-01-WE003

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5d. TASK NUMBER

5e. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Polish Astronautical Society
ul. Krasinskiego 54
Warszawa 01-755
Poland

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0014

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
SPC 01-4003

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking Polish Astronautical Society as follows: The investigator will evaluate full-coverage anti-G trousers the first year and the evaluation of different pressure schedules in the suits the second year. The Acceleration Tolerance Levels (ATL) of centrifuge subjects will be measured with the standard Polish anti-G suit. The ATL will then be measured again with a full-coverage trouser. The order of G-suit will be reversed in some of the subjects. Basic physiological measures will be recorded and ATL will be the primary end point. The percent oxygen saturation values from the cerebral oximeter will be recorded for each acceleration exposure. . In the second year, the contractor will investigate various suit pressures and the effect of those increases/decreases on ATL.

15. SUBJECT TERMS
EOARD, Aerospace Medicine, G-induced Loss of Consciousness, Libelle, anti-G suit

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18, NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			VALERIE E. MARTINDALE, Lt Col, USAF
UNCLAS	UNCLAS	UNCLAS	UL	35	**19b. TELEPHONE NUMBER** *(Include area code)* +44 (0)20 7514 4437

F61776-WE003

ACCELERATION TOLERANCE IMPROVEMENT WITH FULL - COVERAGE ANTI-G SUITS

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FINAL REPORT FOR THE PERIOD
January 2002 to January 2004

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PREFACE

Sustained acceleration research in Poland has been performed at the Polish Air Force Institute of Aviation Medicine (PAFIAM). This Institute is interested in improved G protection for pilots of the aircraft currently flown by the Polish Air Force (PAF) including the MiG-21 and MiG-29. This work was conducted on the PAFIAM centrifuge.

This report documents the experiments conducted under EOARD contract order number F61775-01-WE003 entitled "Acceleration Tolerance Improvement with Full Coverage Anti G Suits." The research was conducted in collaboration with Dr. W.B. Albery from AFRL/HEPG, WPAFB OH.

Within the framework of this work we were studying the effect of the pilot's performance and the physiological effect of wearing different types of anti-G suits used in the PAF, together with an evaluation of the novel Libelle water-augmented anti-G suit also called the self-regulating anti-G suit or SAGE.

The authors wish to extend their appreciation to PAFIAM scientific and technical staff for their work and analysis efforts. Appreciation is expressed to the Director, Dr. Olaf Truszczyński and the Command Staff of the PAFIAM.

INTRODUCTION

The objective of this work was to compare the efficiency of three anti-G suit ensembles. There included the PPK, trousers equipped with bladder system, the WWK, equipped with capstans, long pneumatic tubes that when inflated tighten the fabric to which it is attached, and the Libelle water-augmented anti-G suit. The PPK and WUK suits are currently in use in Polish aviation.

L-1 Anti-G Straining Manuever

The WUK and PPK suits inflate and squeeze the lower torso. A respiratory straining maneuver is used with these suits. The Anti-G Straining Maneuver (AGSM) is a forced exhalation effort against a closed (L-1 maneuver) or partially closed (M-1 maneuver) glottis while tensing leg, arm, and abdominal muscles to maintain vision and consciousness. The higher G levels, to maintain higher intrathoracic pressure, require a greater straining effort. The major problem with the use of the AGSM is that it is fatiguing; it severely limits the duration of high-G that can be tolerated. The respiratory aspect of the AGSM is an adaptation of the Valsalva maneuver that produces a high intrathoracic pressure (100 mmHg maximum). However, unlike the Valsalva maneuver test that challenges the circulatory system to cope with a reduced venous return, the AGSM interrupts the effort at 3 to 4 second intervals with a rapid expiration/inspiration effort (<1 second) that for a brief period of time allows adequate venous return because of a low intrathoracic pressure. Although the head-level P_a falls to nearly zero in conjunction with a lowered thoracic pressure, the period of time is so brief (<1 second) that the brain and retinal tissue oxygen/energy reservoir maintains vision and consciousness. The increase in eye-level blood pressure is immediate with an increase in intrathoracic (esophageal) pressure; i.e., an effective anti-G method.

In order to support venous return during the 3 to 4 second forced exhalation phase, anti-G suit inflation pressure must be four times greater than the intrathoracic pressure. This level of anti-G suit pressure is always present because it increases sufficiently with increasing G. When the AGSM is required, adequate anti-G suit pressure is available; e.g., at 6 G when .5 psi intrathoracic pressure (AGSM) is required, a minimum of 2 psi anti-G suit pressure is needed, but the anti-G suit is pressurized at 6 G to 6 psi. Nine G requires 2 psi of intrathoracic pressure; the anti-G suit pressure is 10 psi, yet only 8 psi is needed for a 4:1 pressure ratio.

Libelle Anti-G Straining Maneuver

The Libelle Straining Maneuver differs from the L-1 in that it is a breathing and straining maneuver where deep breaths are taken at a normal (16 BPM) rate. Breaths are not held and the glottis is not closed. Pressure in the chest is not increased by upper body straining and there is tensing of the lower body only as the abdomen, buttocks, thigh and calf muscles are strained.

G Ensembles

The PPK trousers are equipped with 5 bladders, compressing calves, thighs and the abdomen. The WUK is the tightening anti-G system or the lower part of the "Polish High Altitude Compensatory Suit". This system provides even pressure over the body parts covered (lower extremities). It should be noted that at present only the PPK trousers are used during training of pilots in the Polish centrifuge.

The Libelle suit employs "fluid muscles" to change shape under G and to tighten the fabric of the suit, conferring pressure to the pilot. These fluid muscles are water channels that are filled with water which change shape under G, tightening the suit fabric beside the channels. Deployment of the advanced technology water-augmented Libelle suit could perhaps result in a simpler G protection ensemble that does not need to be connected to the jet.

The purpose of this research is to participate in the USA/Poland Information Exchange Agreement (IEA) via the joint study of the efficiency of a new G protection ensemble (Libelle), which is also being evaluated by the USAF. A comparison of the three types of anti-G suits is interesting from a physiological point of view and is of interest to Polish aviation authorities.

BACKGROUND

As a result of establishing scientific contacts with Dr. R. Burton, former Chief Scientist of AFRL/HE, and Dr. W. Albery, manager of the Wright-Patterson Air Force Base centrifuge facility in Dayton OH, there was initiated co-operative project "Acceleration tolerance improvement with full coverage anti – G suits".

This study was broadened by conducting comparative research with bladder type suit (PPK) and capstan type suit (WUK), used in the Polish Air Force, and the latest generation of the water augmented Libelle suit.

The goal of this study was to find the means to increase Polish pilot's G tolerance, which according to NATO requirements should be 9 G for 15 seconds as tested during centrifuge training. Poland is acquiring all of Germany's MiG 29 fighters and has recently purchased 48 F-16s from the U.S. Studies carried out in the German centrifuge at Königsbrück (with the Libelle) as well as at Brooks City Base(COMBAT EDGE plus ATAGS) showed that there is possibility of reaching sustained accelerations of 10 – 12 G for several seconds. It should be noted that the Libelle suits are deployed in the German MiG–29 aircraft and have been certified for the Eurofighter (Germany only).

During the last year the USAF has initiated a Foreign Comparative Test (FCT) of the Libelle suit. Currently AFRL has begun centrifuge testing of the Libelle.

METHODS

The study was performed in two stages. Stage one assessed how well the current Polish A-G suits can protect the pilot against acceleration. The second stage consisted of a closed loop evaluation where we compared Polish suits and the water-augmented A-G suit “Libelle”.

G SUITS

The PPK types of G trousers are equipped with 5 bladders, compressing calves, thighs and the abdomen. The WUK suit is the lower part of the Polish “High Altitude Compensatory Suit”. It is equipped with an additional tightening system, via capstones, which equally compress the whole surface of the lower body part and abdomen (fig.1)

Fig. 1. Anti-G suits used in Polish aviation – left is PPK – right is WUK

Centrifuge

The examinations were carried out in the Polish human centrifuge (Fig. 2). It has a 9.2 m arm with an onset rate of 3.5 G/s. It is fully computerized and can operate in the open loop mode using selected programs or in the closed loop mode to emulate flight conditions. In the closed loop mode, the pilot controls the G via a flight stick.

Fig 2 - Polish human centrifuge

Subjects and Training

10 healthy volunteers (19-22 years old) were examined according to the following procedure:

1. General health examined by the PAFIAM Aviation Medical Board.
2. Classroom instruction about a physiological change in the human body during +Gz and the method of examination.
3. Initial training in the centrifuge, including G protection maneuvers and communication, safety precautions, cooperation with the examiner, and reacting to the presented test and visual stimuli.

The training was performed with the pilot relaxed and straining at G levels of 2.5 G – 3 G for 30 s. The centrifugation was repeated until the volunteers learned how to respond correctly during acceleration. The follow up

Acceleration Tolerance Level (ATL) examination was carried out using gradual onset rate (GOR) and rapid onset rate (ROR) profiles (fig. 3).

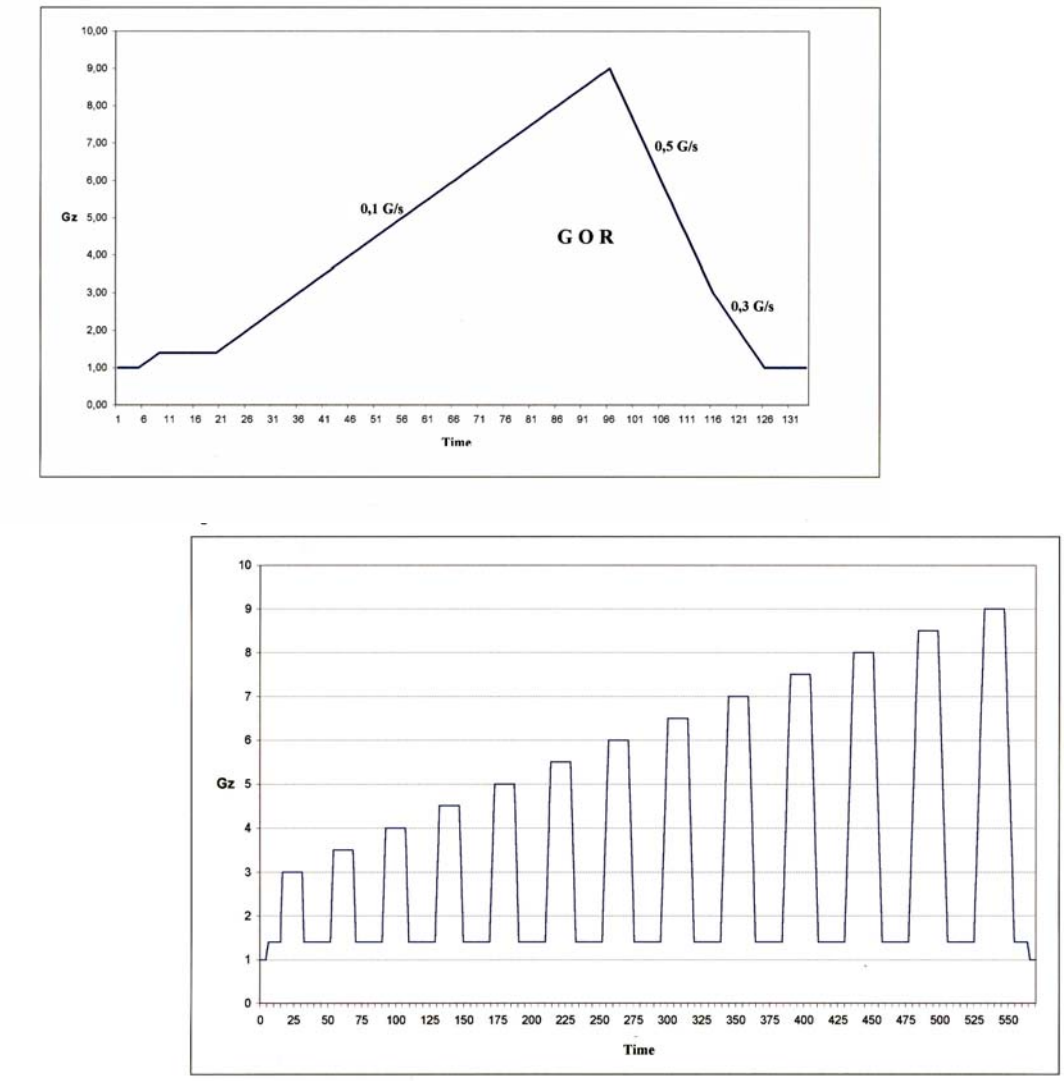


Fig 3 - Programs of GOR and ROR profiles

In GOR G-load increased at .1G/s until peripheral vision was narrowed to 50^{o}. The ROR profiles consisted of numerous exposures increasing in steps of .5G. The acceleration onset rate was 1G/s and the time at peak G level was 12 seconds. The breaks between each cycle were also 12 seconds. This acceleration profile is termed the "ROR Congested Intervals Program".

In all examinations the peripheral vision loss, confirmed by the interruption of ear vascular pulsation (ear oximeter), constituted a criterion of ATL evaluation (fig. 4). Heart rate was also recorded. (fig. 5).

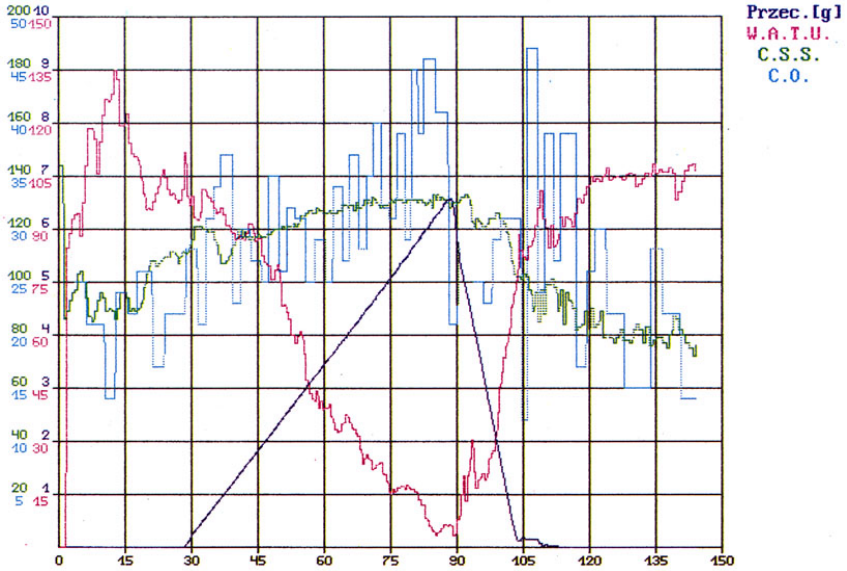


Fig. 4. Ear vascular amplitude decrease in dependence of G- increase, HR and breathing frequency

When the amplitude decreases to near “0” – visual disturbances occur.

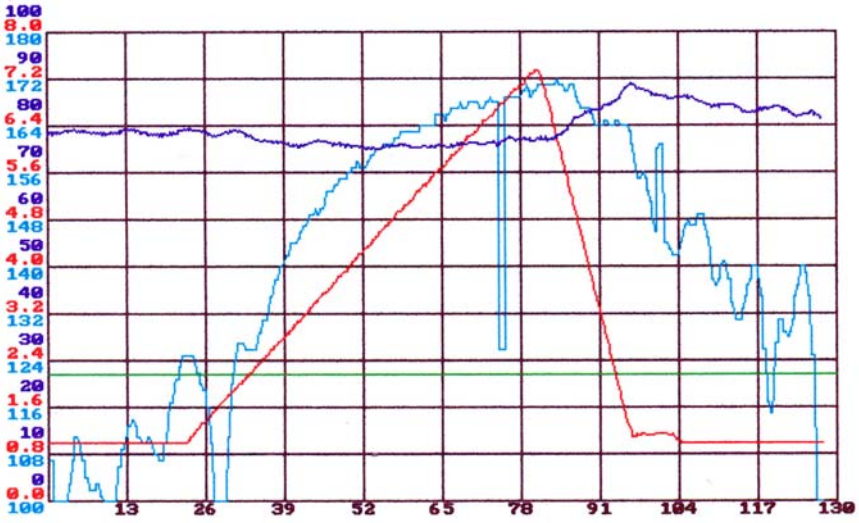


Fig. 5 Simultaneous HR increase with G onset

All subjects used the normal L-1 straining maneuver.

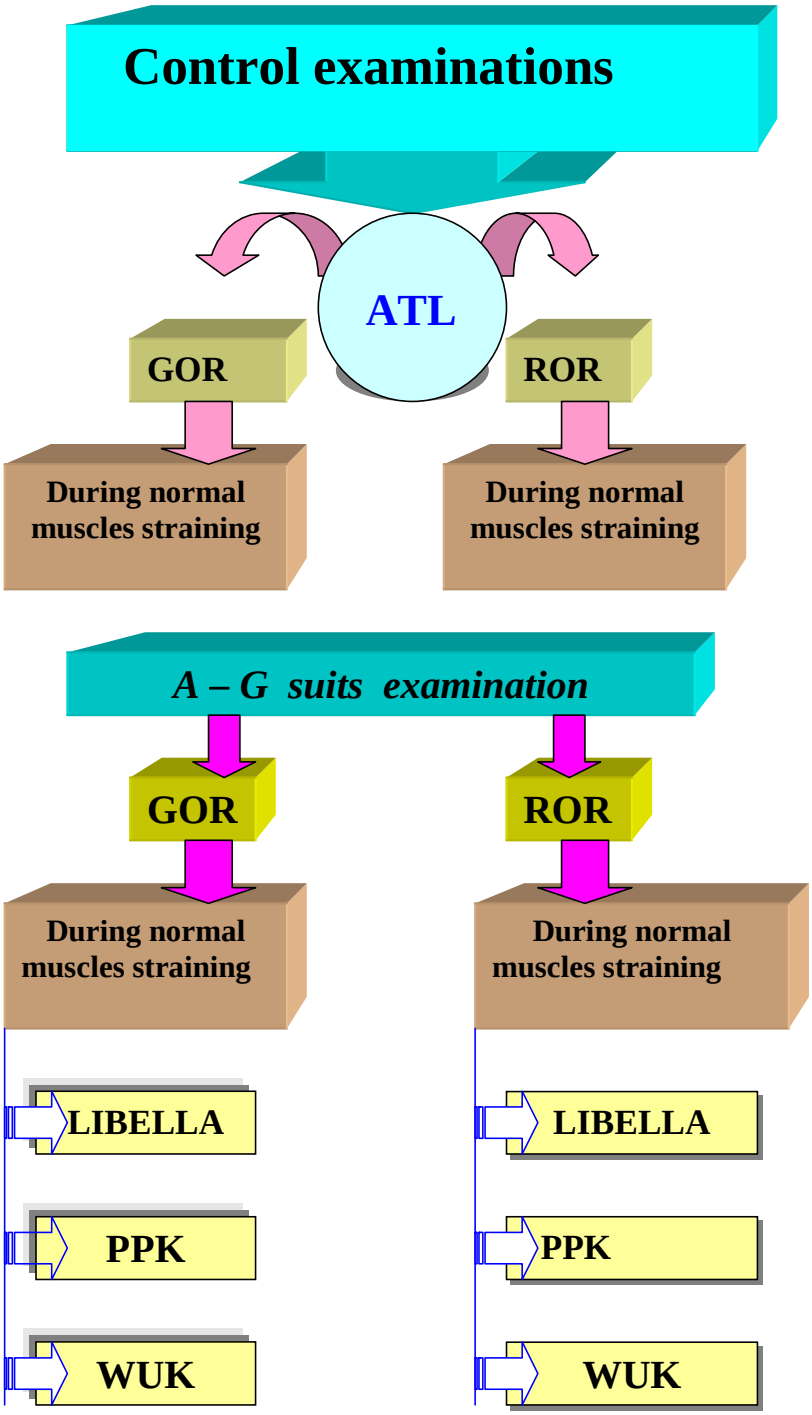


Fig. 6. Examination program

The following parameters were recorded during this study:

- ECG with V_2 V_5 leads;
- Absolute HR values, also in a form of the curve, presented simultaneously with the acceleration onset curve (fig. 5);
- ear lobe vascular pulsation amplitude (fig. 4);
- breathing frequency EMG;

- oculomotor responses to light stimuli presented in the peripheral visual field;
- G values in x, y, z axis.

The Libelle G Suit

The autonomous system of Libelle reportedly exerts the right counter-pressure on every part of the pilot's body during acceleration and reacts instantly, even to high G-onset rates. Four double membranes or channels are filled with fluids, extend from the shoulders to the ankles. Under normal gravity conditions these so called fluid muscles are almost flat. As G increases, the hydrostatic pressure increases causing the fluid muscles to contract and take the shape of the hose. The contraction generated is transferred to a non-stretch material surrounding the pilot's body and effectively stops the blood from pooling in the lower body and extremities. The technology enables the pilot to maintain a high level of awareness and eliminates arm and foot pain at high G.

The coverall consists of fire resistant Nomex and represents the outer layer of the Libelle. Recently, the Libelle has been qualified by the German Air Force as outer garment by conducting wind blast and ejection seat trials up to a speed of 600 KEAS and substitutes for the standard flight suit for the mission.

The fabric of Libelle is permeable to air and keeps the pilot's skin dry. During missions which require protection against immersion or NBC, these suits will be worn on top of the Libelle. The system easily adapts to different types of aircraft since Libelle does not contain any interfaces at all. Even the requirement of high altitude protection – especially defined for the 4th generation aircraft – has been integrated into the Libelle concept.

In the second experiment, we compared the Libelle suit with the Polish anti-G suits. During all of the tests, the closed loop method was used. The Libelle study was carried out according to an Autofluglibelle company program. Due to the need of familiarization with centrifuge during closed loop, the pilots underwent a short training prior to the ATL examination. The acceleration level was limited to 4 G to avoid unnecessary tiring. An example of the training is presented in figure 7.

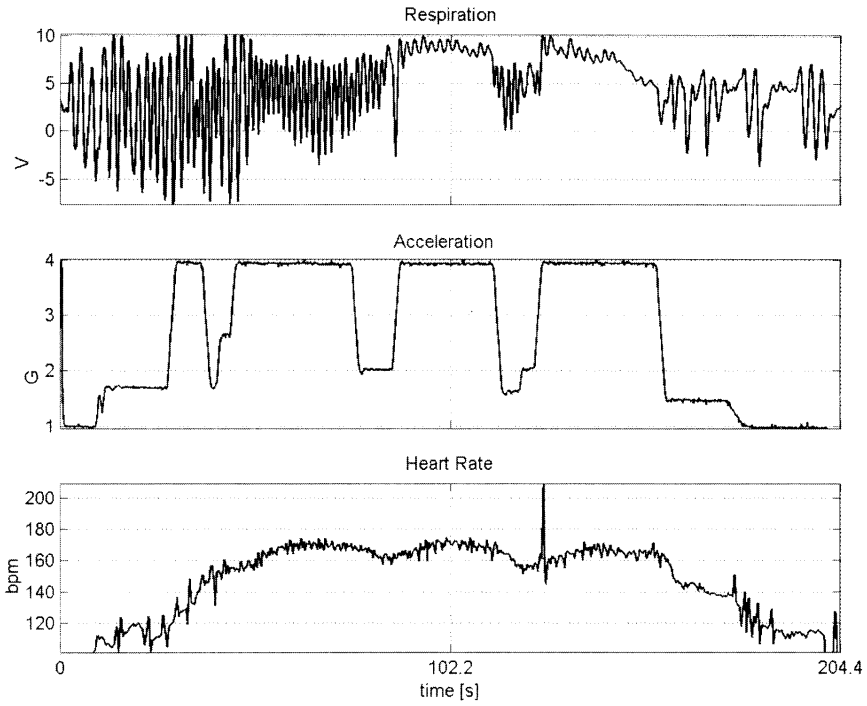


Fig. 7. Example of training – breathing (top), G (middle), HR (bottom).

During all centrifuge profiles the same parameters were monitored and recorded as during the first experiment.

Subjects were instructed to command the maximal G onset rate of the Polish centrifuge. During centrifugation, Polish pilots were allowed to perform the standard anti-G straining maneuver (L-1) and during the Libelle examination, the Libelle Straining Maneuver (LSM). ATL assessment criterion was visual field disturbances or termination from other reasons (medical or physical)

RESULTS and DISCUSSION

EXPERIMENT I:

During the first experiment, it was found, compared to the follow up examinations, that +Gz ATL in the WUK is higher than in the PPK suit – by 0.4 G under GOR, and 0.3 G under ROR profile. The results are presented in tables I and II.

TABLE I: ATL COMPARISION IN GOR PROGRAM
(n = 10)

TEST	ATL	Difference	Stat.
Control (1)	4.75 ± 0.51		
PPK (2)	5.94 ± 0.55	(1 – 2) 1.19 G	p< 0.01
WUK (3)	6.36 ± 0.58	(1 - 3) 1.60 G	p< 0.01

ATL COMPARISION IN ROR PROGRAM
(n = 10)

TEST	ATL	Difference	Stat.
Control (1)	4.60 ± 0.66		
PPK (2)	5.70 ± 0.53	(1 – 2) 1.10 G	p< 0.01
WUK (3)	6.00 ± 0.50	(1 - 3) 1.40 G	p< 0.01

Table I shows that the PPK suit increases ATL by 1.19 G, while the WUK suit increases it by 1.6 G in the GOR profile. The difference between the PPK and the WUK is 0.41 G and is significant ($p<0.05$). During the ROR exposure, the difference was 0.3 G.

HR changes and the number of tolerated intervals are presented in Table II as well as the HR changes during ROR profile.

TEST	START	I N T E R V A L S													
	1 G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
CONTROL	119,9 ±11,8 n= 10	130,7 ±11,6 n =10	135,9 ±12,6 n = 10	133,6 ±15,0 n = 10	130,7 ±15,5 n =10	133,9 ±14,5 n = 10	137,9 ±12,4 n = 8	140,1 ±15,6 n = 6	14 3,3 ±15,7 n = 6	146,6 ±16,5 n = 5					
PPK	114.2 ± 14,1 n = 10	126.2 ± 10.2 n = 10	119,5 ± 13,3 n = 10	119,8 ± 14,0 n = 10	120,9 ±13,1 n = 10	122,6 ± 12,7 n = 10	123,8 ± 11,2 n = 10	125,9 ± 11,8 n = 10	130,7 ± 10,7 n = 9	131,5 ± 11,6 n = 8	129,5 ±12,3 n = 8	133,3 ±11,0 n = 8	133,8 10,9 n = 8	131,1 ±15 ,7 n = 7	132,7 ±15,1 n = 5
WUK	114,4 ± 13,0 n = 10	122,2 ± 12,5 n = 10	116,6 ± 12,9 n = 10	119,3 ± 13,3 n = 10	117,5 ± 13,8 n = 10	121,8 ± 10,6 n = 10	123,4 9,5 n = 10	124,5 ± 12 n = 10	125,9 ± 12,1 n= 10	128,2 ± 9,5 n = 9	131,2 ± 12,9 n = 9	132,5 ± 8,9 n = 8	130,2 ± 7,2 n = 7	133,2 6,9 n = 7	134,0 ±6,0 n = 6

Table II. Heart rate changes registrated during ROR acceleration program and number tolerated intervals by the subjects in different tests of interval program (n=10).

Comparison of the HR values, recorded at baseline, with the values of this index, obtained during subsequent intervals of each test, shows significant differences. During the follow up examination, the increase in HR, as compared to the moment of peripheral vision loss, was 26.7 beats per minute. Using PPK and WUK suits this difference was reduced by 18.5 and 19.6 respectively. In the next figure (fig.8), the mean differences between HR values obtained during the control examination without an anti-G suit (unprotected) and during the condition of both anti-G suits (protected), are presented.

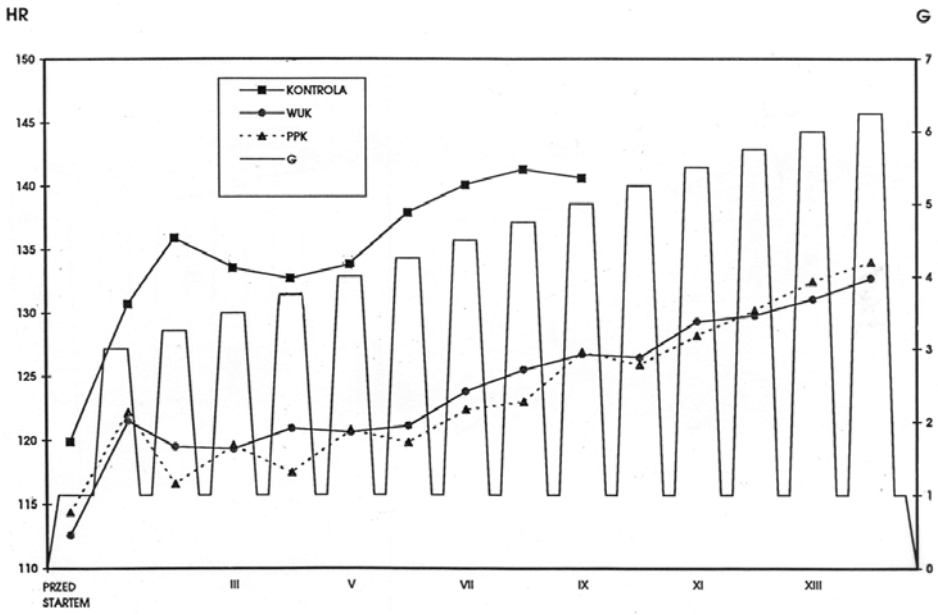


Fig. 8. HR changes during Experiment I.

Examination of the circulatory system has shown that using both types of anti-G suits; result in similar lower HR increase, although the effect of WUK type was manifested by deeper more increase of this ratio.

It is worth noting that the number of intervals tolerated by the subjects was different in each test. During the control examination, five subjects obtained the highest ATL in the IX interval. The same number of subjects obtained ATL in the XIV interval when wearing PPK trousers. Six subjects wearing WUK also obtained ATL in the XIV interval.

The increase in the number of the tolerated intervals in subjects wearing both types of A-G suits as compared to the values obtained during the control examination, confirm the effectiveness of these suits.

Significant differences occurred in the ear lobe vascular pulsation amplitude values. In most of the subjects who do not wear A-G suits, a pronounced decompensation phase of the circulatory system occurs, turning into a compensation phase of the circulatory system during the same level of acceleration. During the next intervals, these changes are not so pronounced and the compensatory pulsation phase disappears for the second time during the ATL. In subjects wearing PPK trousers and WUK suits, changes in ear lobe pulsation amplitude do not occur during the initial intervals. This amplitude decreases gradually and disappears in the last interval when reaching ATL. The ear vascular pulsation amplitude was lower when using the WUK A-G suit.

The differences taken from one of volunteer are presented in the figure 9.

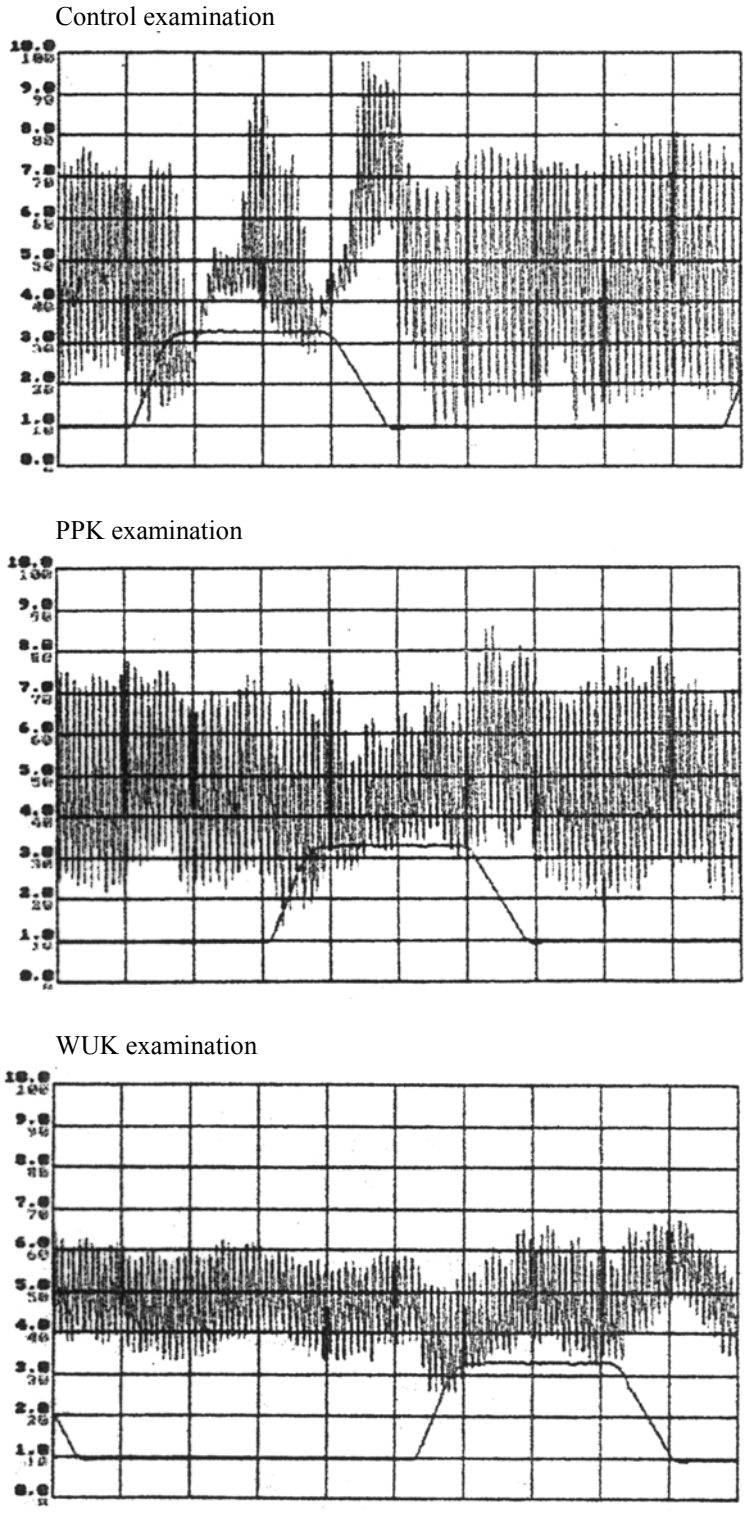


Fig. 9. Ear vascular pulsation amplitude changes

After leaving the centrifuge cabin the subjects expressed their opinion about peripheral vision loss, the efficacy of G protection and the effectiveness and comfort of both types of suits. There were complaints resulting from using

the PPK and the WUK (fig. 10). The WUK Suit received a more favorable rating than the PPK Suit.

Subjects pointed out, that in contrast to the WUK anti-G suit; during maximal filling of the pressure system of the PPK anti-G trousers, they experienced pain. The prevalent opinion of the subjects donning the WUK was that it required more effort and took more time. Subjective assessment of anti-G protection was unequivocal.

THE CLOSED LOOP CENTRIFUGE EXAMINATION

Familiarization program for closed loop of centrifuge.

Results of the physiological measurements of each pilot are shown in figures 8 to 20. Changes of parameters were analyzed accordingly to phases of exposure.

Phases: before acceleration, during acceleration and periods between exposures were considered. Results presented are mean values of parameters in the time periods shown. It should be noted, that all participants were using the closed loop capability of centrifuge for the first time in their career. The familiarization program was performed with no predetermined profile (each pilot had full control at will).

Figures 8, 9, 10, and 11 show parameters in each subject during initial training for closed loop profiles, with the centrifuge set at a maximum of 4G.

Subject 1 (S.S.).

Analysis of parameters during training (figures 8 and 9), it is apparent that there were many changes in acceleration which had considerable impact on HR values during training.

	F01	F02	F03	F04	F05	F06	F07	F08
Gz	1.05	3.90	1.77	4.91	2.18	5.44	2.19	5.94
SD	0.01	0.04	0.76	0.04	1.26	0.01	1.30	0.03
HR	106.53	137.11	133.13	139.04	145.82	143.11	139.34	139.50
SD	4.53	2.69	5.60	5.58	5.37	2.32	10.16	3.42

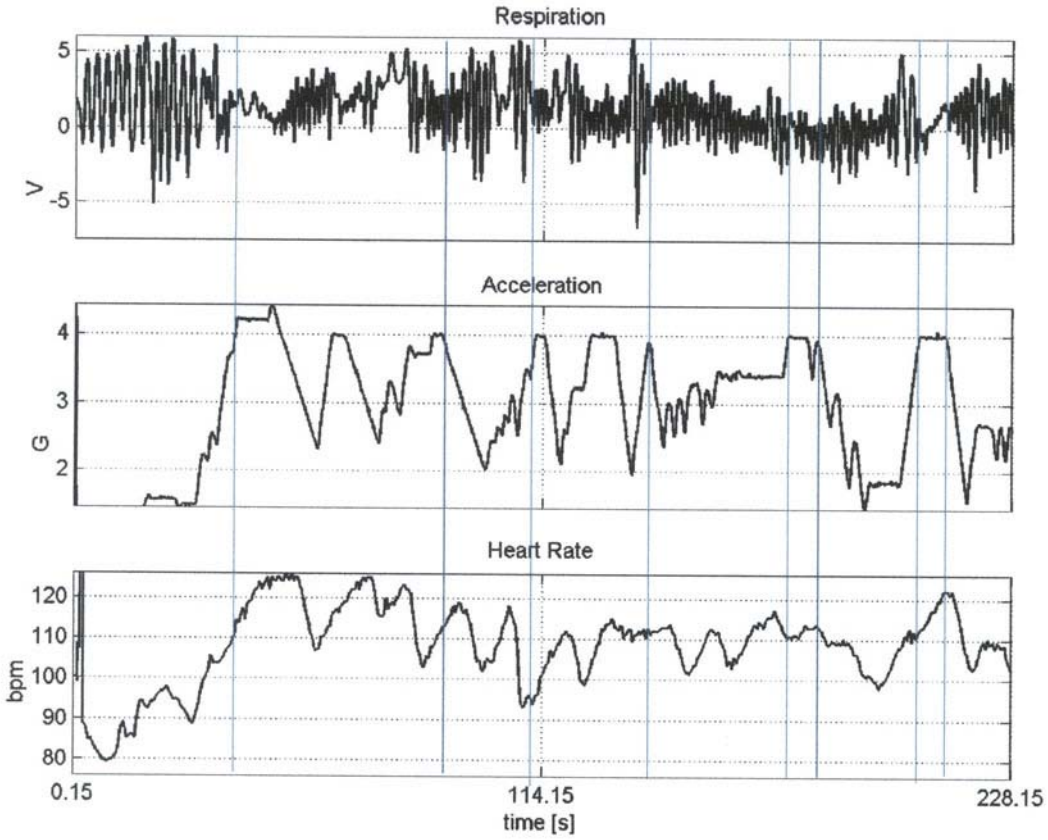


Figure 8. Training of Subject 1 in PPK A-G trousers.

Ślusarz 1/2

	F09	F10	F11	F12	F13
Gz	2.36	6.44	2.49	6.96	1.01
SD	1.51	0.02	1.65	0.03	0.01
HR	133.38	137.94	137.26	141.39	109.13
SD	10.17	4.48	4.74	3.72	11.99

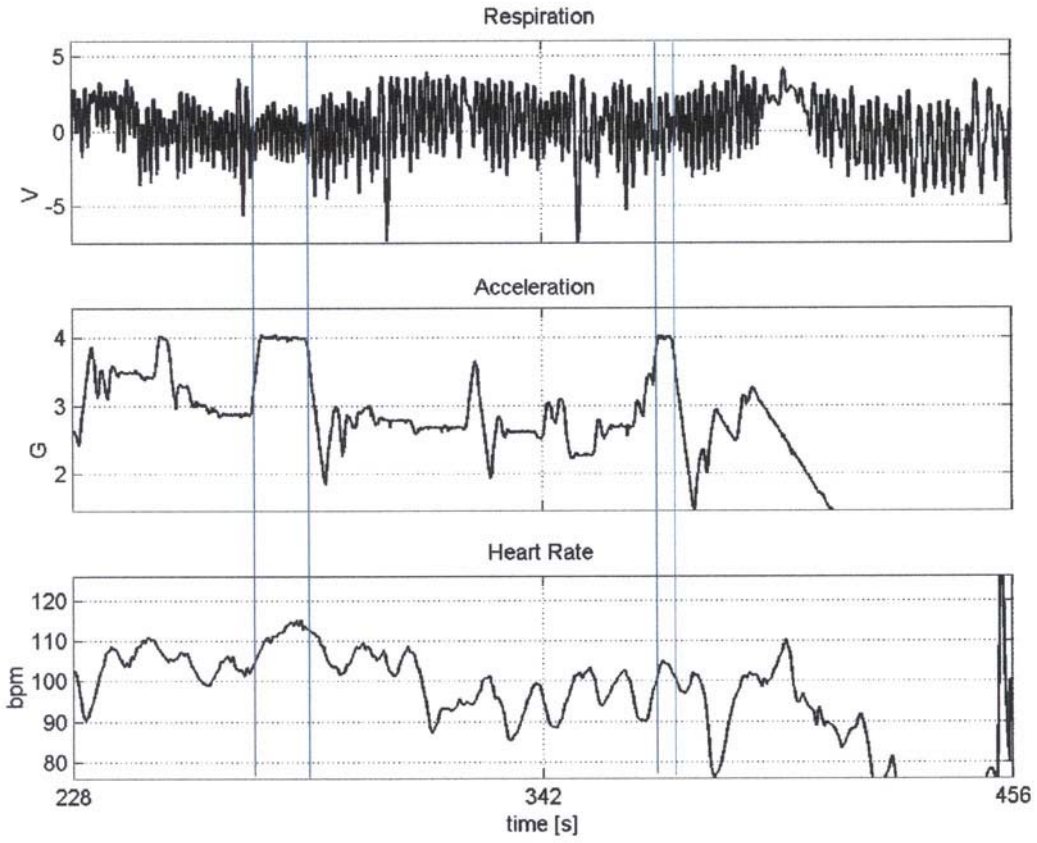


Figure 9. Continuation of training of Subject 1 in PPK A-G trousers.

Variability of HR in this subject was in the range of 90 to 130 bpm. In the initial phase of centrifuge training, his breathing rhythm was unstable with variable amplitude. The pilot commanded numerous changes in G and tried to perform an L-1 maneuver.

2. Subject 2 (K.Z.).

Recorded values for this pilot are shown on Figure 7 and 10

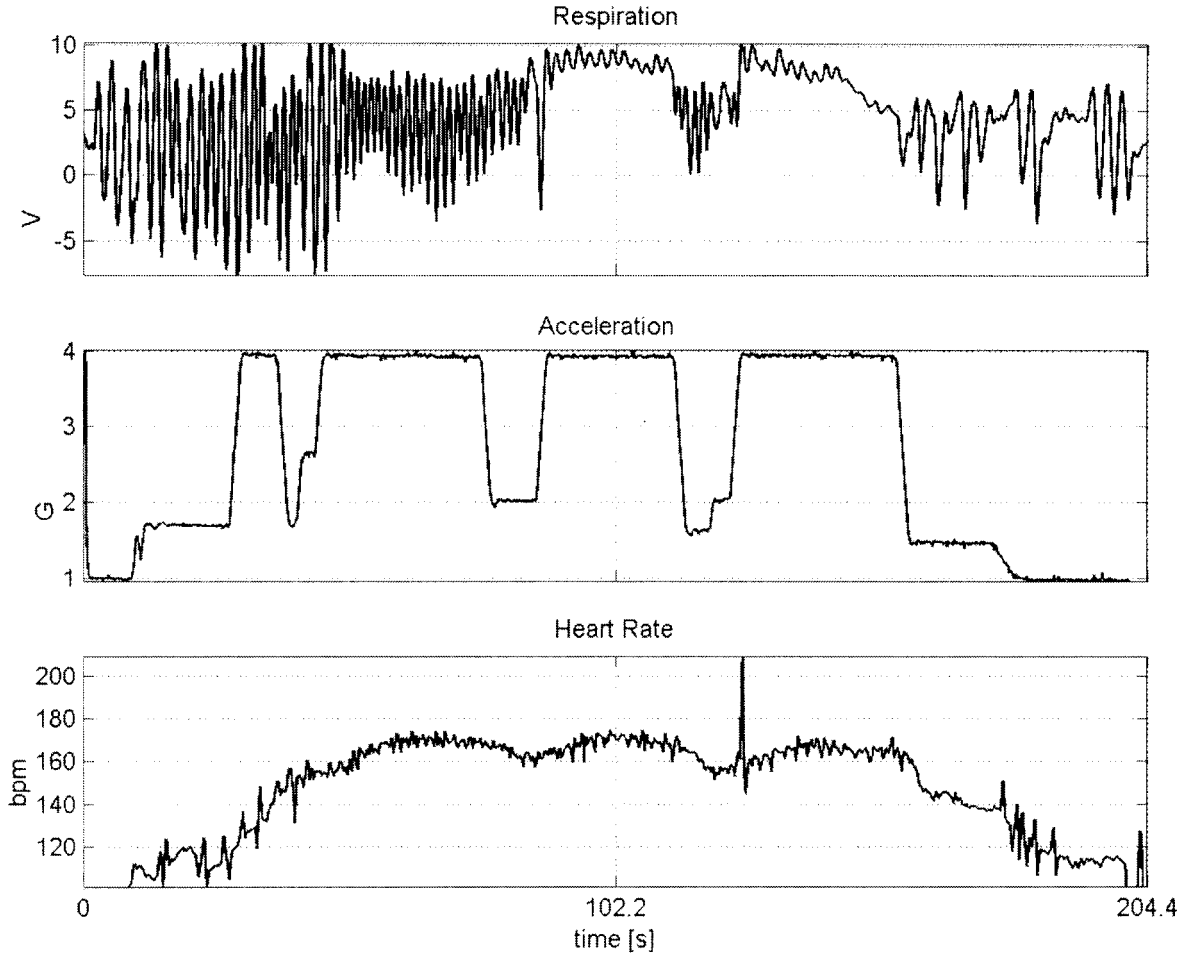


Figure 7. Training of Subject 2 on to 4G.

	F01	F02	F03	F04	F05	F06	F07	F08
Gz	0.99	3.93	3.93	2.45	3.92	2.24	3.94	0.97
SD	0.01	0.06	0.02	0.69	0.01	0.75	0.02	0.02
HR	93.56	131.36	166.00	164.82	168.63	160.46	164.69	114.91
SD	3.29	5.83	5.36	3.20	3.09	4.93	5.39	4.24

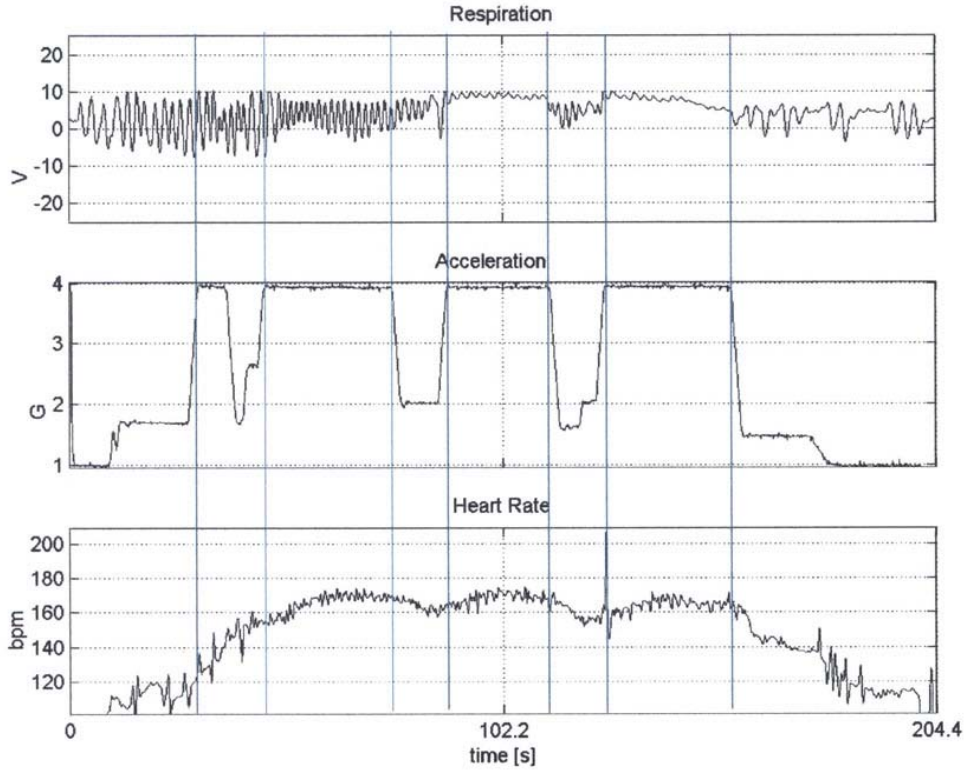


Figure 10 Continuation of training of Subject 2 to 4G.

During this training period, the pilot commanded high G onset with prolonged acceleration time. In subsequent exposures, changes of breathing rhythm in peaks of acceleration are clearly noticeable (F01, F03 & F04). These changes are most probably associated with strong muscle straining. It is also is indicated by HR values, which from the beginning of exposure is increasing as a function of increasing G from 93.5 bpm (F01, F02) to around 160 bpm in 3 prolonged cycles of maximal acceleration (F03, F05, F07) .

Small decreases in HR between acceleration peaks indicates strong intervals of straining performed even in periods of acceleration decay. A stable and low amplitude breathing pattern indicates prolonged L-1 maneuvers.

3. Subject 3 (R.B.) - Exposure in Libelle G suit.

This subject's training schedule is shown in Fig 11.

Brandis 1

	F01	F02	F03	F04	F05	F06	F07
Gz	1,01	3,93	2,65	3,77	3,58	5,61	1,00
SD	0,01	0,02	0,48	0,33	0,81	0,60	0,02
HR	96,57	105,62	102,46	104,98	108,29	134,13	118,23
SD	2,33	6,94	3,08	4,62	8,16	8,73	4,32

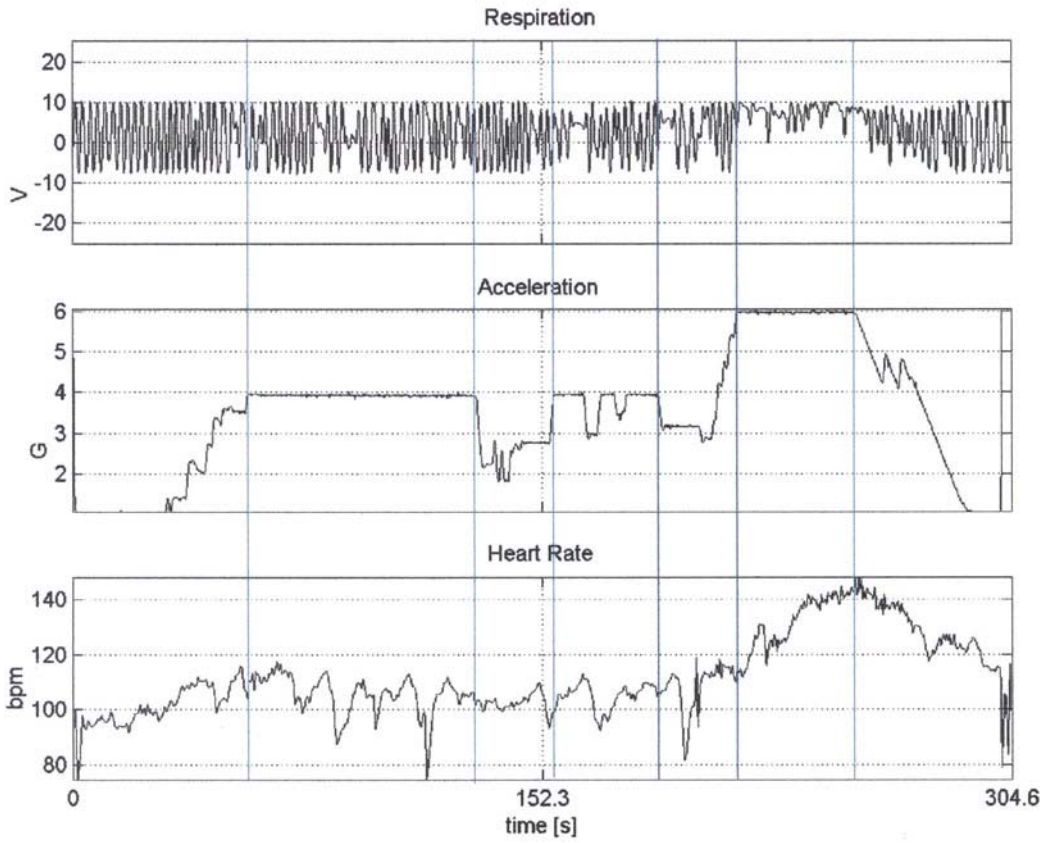


Figure 11. Training of pilot wearing Libelle G suit.

On the pilot's request, the centrifuge was set to a maximum level of 6G. During training, he commanded a prolonged acceleration of 4 and 6G. During the maximal acceleration the pilot changed his breathing pattern a few times, which is visible on records for breathing amplitude and HR.

HR changes in first phase of training at 4G were small (in the range from 96 to 108 bpm). During 6G we have recorded the changes in the breathing

pattern. They were compatible with the recommended breathing pattern of the Libelle manufacturer.

The pilot was inhaling deeply and slowly, with low amplitude through the mouth and exhaling through the nose. This breathing pattern was easily recorded because there was no upper body straining. (Fig. 12)

It should be noted that average HR during training was much lower than in previous subjects with average value of 134 bpm (F06).Continuation of training was performed with the acceleration level set at 9G (Fig. 12).

Brandis 2

	F01	F02	F03	F04	F05	F06	F07
Gz	1.01	3.86	2.87	5.94	3.04	7.01	1.01
SD	0.01	0.17	1.25	0.17	1.28	0.01	0.02
HR	101.32	114.62	113.30	137.28	133.27	147.24	121.21
SD	3.84	9.78	9.44	5.61	8.68	5.72	7.05

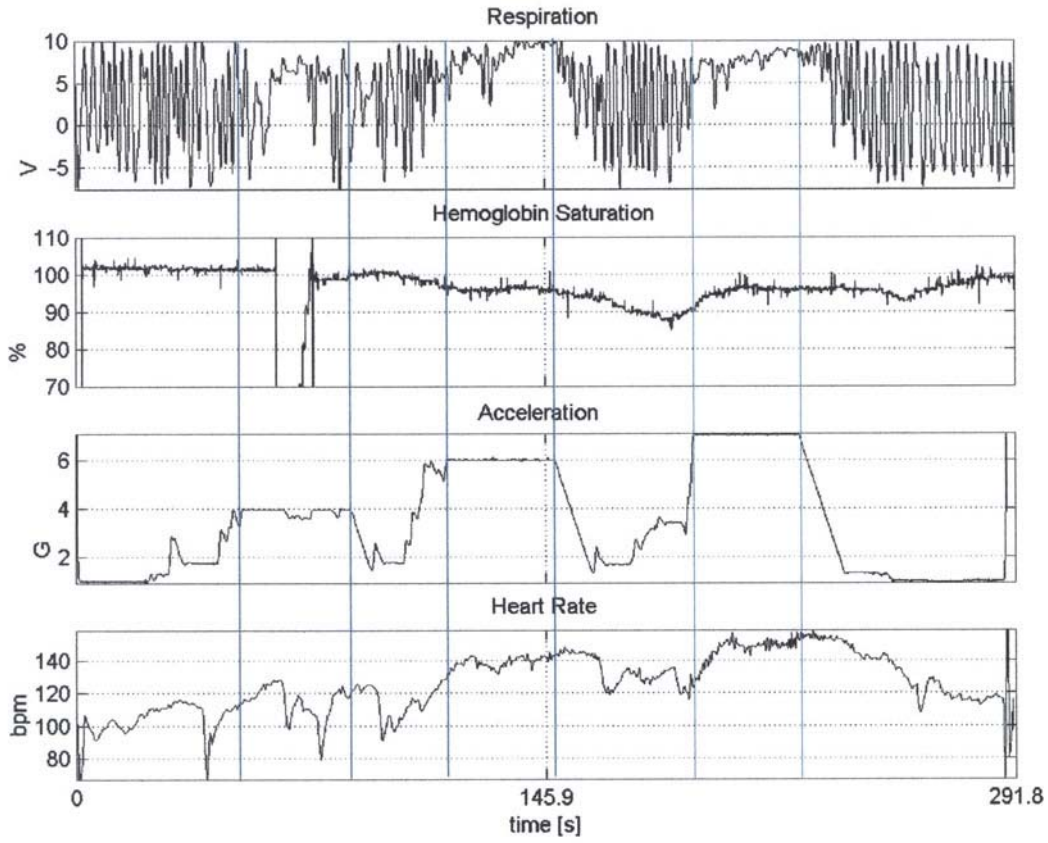


Figure 12. Continuation of training of the Libelle equipped pilot.

In the subsequent phases of sustained acceleration with average values of 3.86G, 5.94G and 7.1G (F02, F04, F06) the pilot performed the Libelle Straining Maneuver (LSM). During acceleration phases with average values of 5.9G and

7.1G, HR was stable and during the final interval the average value was 147 bpm. After leaving the centrifuge cockpit, the subject did not show any signs of fatigue and had no complaints.

96 Exposures

In this stage of our study, the goal was to reach 9 G for 15 sec by the Polish pilots using the PPG Anti-G suit. The same requirement was made to the pilot using the Libelle Anti-G suit. Polish pilots were subjected to ROR profile with acceleration set in intervals increasing in 0.5 G. The pilot wearing the Libelle anti-G suit was exposed to the profiles developed by Autofluglibelle. During the last profiles, the centrifuge parameters were set to reach 9 G with the maximum G onset available on Polish centrifuge. Maximum sustained acceleration allowed was set on 9 G.

1. Subject 1

First examination

In his first centrifugation, subject one had average acceleration value of approximately 7 G (F12) and experienced peripheral vision loss of 50°. While under sustained acceleration, he was performing the L-1 maneuver, which was registered and is visible on Fig. 13.

Ślusarz 2

	F01	F02	F03	F04	F05	F06	F07	F08
Gz	1.05	3.90	1.95	4.91	2.12	5.44	2.20	5.94
SD	0.01	0.03	1.01	0.01	1.21	0.02	1.32	0.02
HR	107.11	136.76	133.21	139.97	145.72	143.25	139.12	139.64
SD	4.79	2.46	5.56	5.64	5.39	2.42	10.12	3.35

	F09	F10	F11	F12	F13
Gz	2.36	6.44	2.42	6.96	1.01
SD	1.51	0.02	1.59	0.03	0.01
HR	133.38	138.08	137.17	141.55	109.13
SD	10.17	4.50	4.71	3.77	11.99

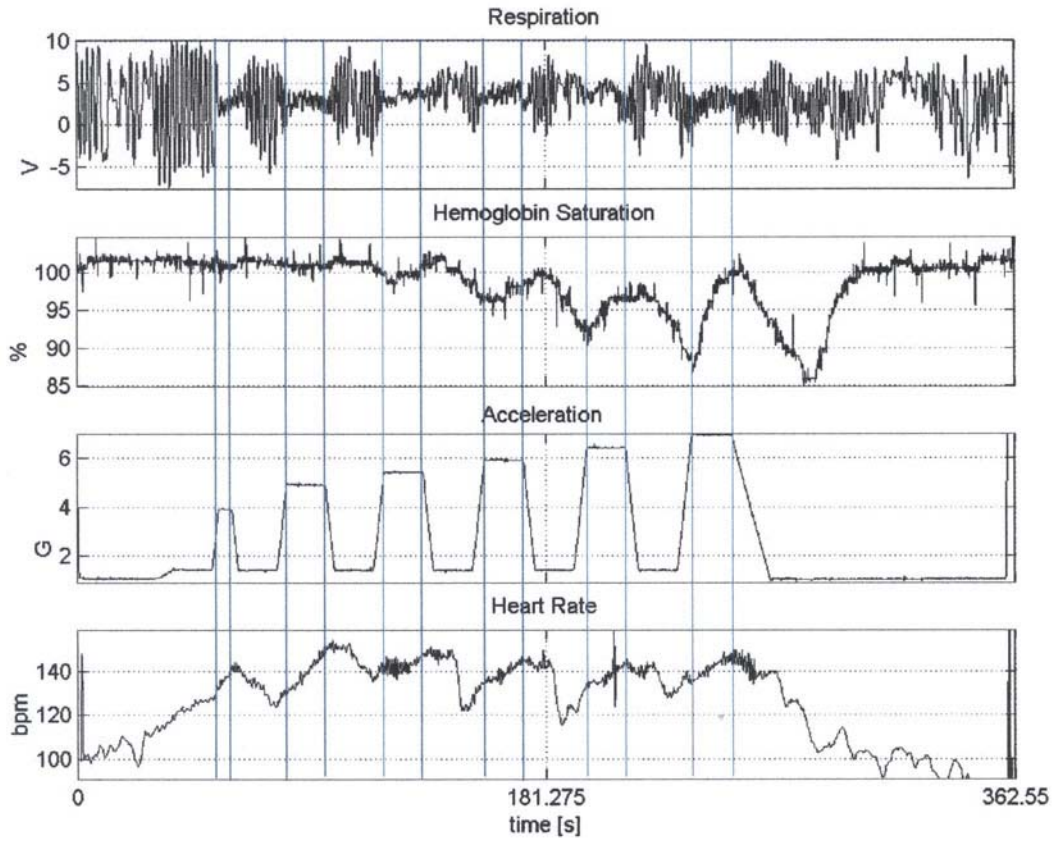


Fig. 13. Subject 1 interval profile -

The L-1 had an impact on HR, which increased in each phase. In comparison to the initial intervals, the small decrease in HR can be noticed. Analyzing breathing patterns shows a decrease in efficiency of the L-1 maneuver. Increase of hemodynamic disturbances can be assessed by the oxygen saturation of hemoglobin, which gradually decreased, reaching 85% during the last phase. In this examination 6.5 G was the maximum G.

Second examination

After one hour of rest, the subject again performed the interval profile. (Fig. 14)

Ślusarz 3

	F01	F02	F03	F04	F05	F06	F07	F08	F09	F10
Gz	1.01	3.89	1.89	4.91	2.13	5.42	2.09	5.94	2.34	6.45
SD	0.02	0.01	0.93	0.02	1.42	0.03	1.23	0.02	1.51	0.02
HR	84.23	107.37	99.11	115.50	101.29	131.50	130.70	140.13	134.11	146.25
SD	4.72	1.16	6.69	6.98	15.51	7.55	6.91	5.33	8.98	8.40

	F11	F12	F13	F14	F15
Gz	2.62	6.98	2.61	7.48	1.00
SD	1.82	0.01	1.82	0.06	0.02
HR	144.83	151.75	146.10	156.00	112.29
SD	6.83	6.11	10.35	7.08	13.98

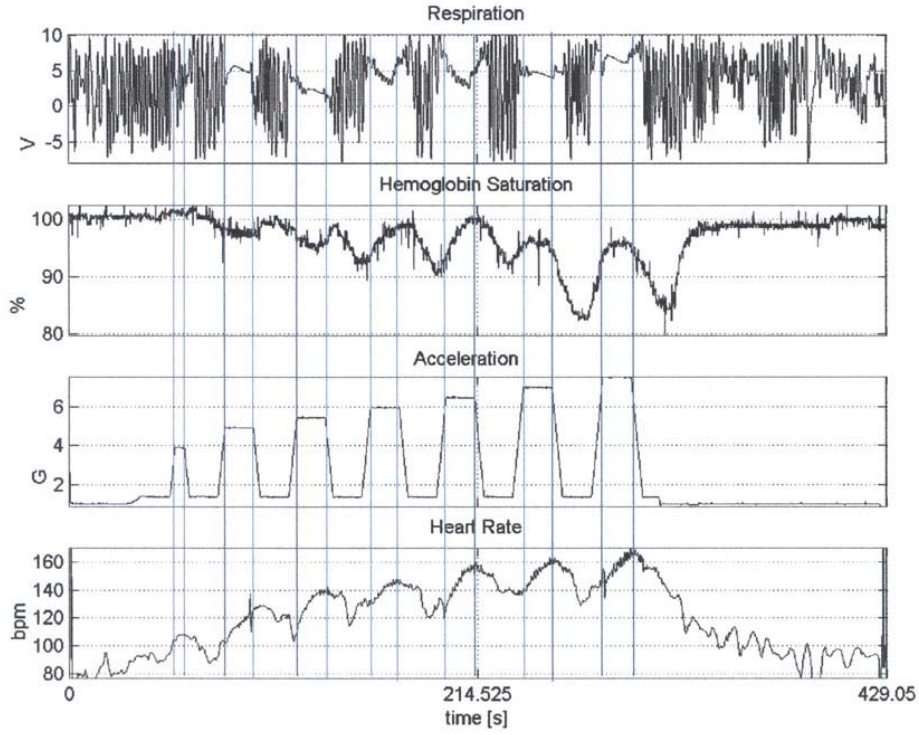


Fig. 14 Second examination of subject 1

In this examination it can be observed that L-1 maneuver is more efficient, which is represented by a proportional increase of all registered parameters. Average HR in the last interval was 156 bpm and decrease in oxygen hemoglobin saturation during last two intervals; 82% and 83% respectively. Peripheral light loss of 50° was reached during the last interval.

III examination

	F01	F02	F03	F04	F05	F06	F07
Gz	1.68	4.75	3.27	6.50	2.38	7.65	0.99
SD	0.01	0.07	0.96	0.59	1.06	0.26	0.02
HR	96.07	122.26	118.07	130.97	127.06	147.41	111.12
SD	4.62	5.08	7.62	10.30	8.88	10.67	3.73

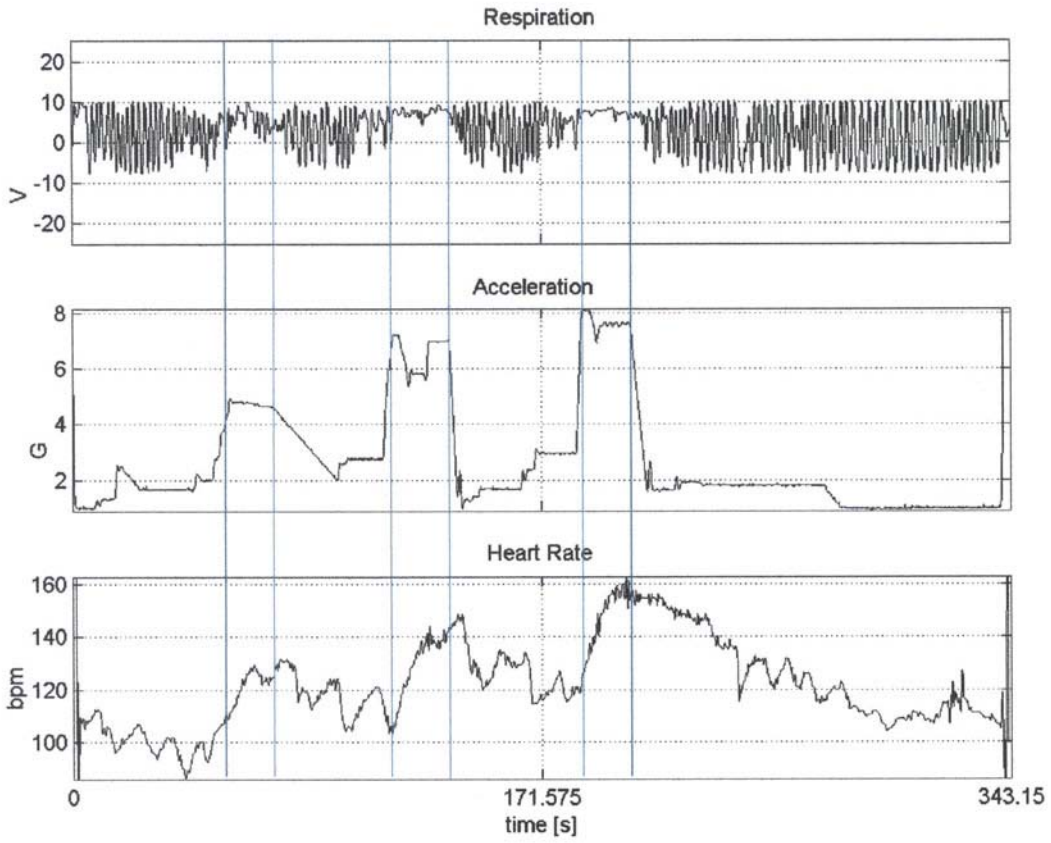


Fig. 15 Subject 1 examination while trying to reach maximum G

The goal of this examination was to reach maximum acceleration of 9 G with the maximum G onset rate available on Polish centrifuge. During this examination subject 1 performed three intervals with average G values of 4.75 G (F02), 6.5 G (F04), and 7.65 G (F 06). During the onset of acceleration subject 1 was performing the L-1 maneuver, in which breathing phases were prolonged. HR was changing accordingly to his breathing and increasing in the rest periods between L-1 intervals. Visual disturbances appeared at 7.65 G. This relatively low value of G tolerance was the result of lack of a training in the anti-G straining maneuver and proper correlation of breathing and straining in the L-1 maneuver. It should be noted that subject 1 during his annual examination had 7.6 G in GOR and 6.1 G in ROR (without an anti-G suit).

2. Subject 2 (Z.K.)

I examination

During the ROR profile (Fig. 16) subject 2 was performing an L-1 maneuver in all the intervals. It correlated with HR changes, breathing pattern and oxygen hemoglobin saturation.

Zięć 3

	F01	F02	F03	F04	F05	F06	F07	F08
Gz	1.01	3.90	1.94	4.91	2.01	5.43	2.13	5.94
SD	0.02	0.02	1.00	0.01	1.10	0.02	1.27	0.02
HR	95.75	120.51	122.33	134.50	123.73	140.86	126.98	146.59
SD	6.15	1.45	3.55	6.02	9.72	5.85	10.02	5.50

	F09	F10	F11	F12	F13	F14	F15	F16	F17
Gz	2.33	6.44	2.49	6.97	2.66	7.49	2.83	8.01	1.01
SD	1.51	0.01	1.69	0.02	1.89	0.02	2.04	0.03	0.02
HR	137.13	150.03	139.02	153.24	144.99	157.11	151.40	162.10	133.15
SD	10.33	3.43	7.84	4.88	6.43	6.07	7.09	6.60	15.60

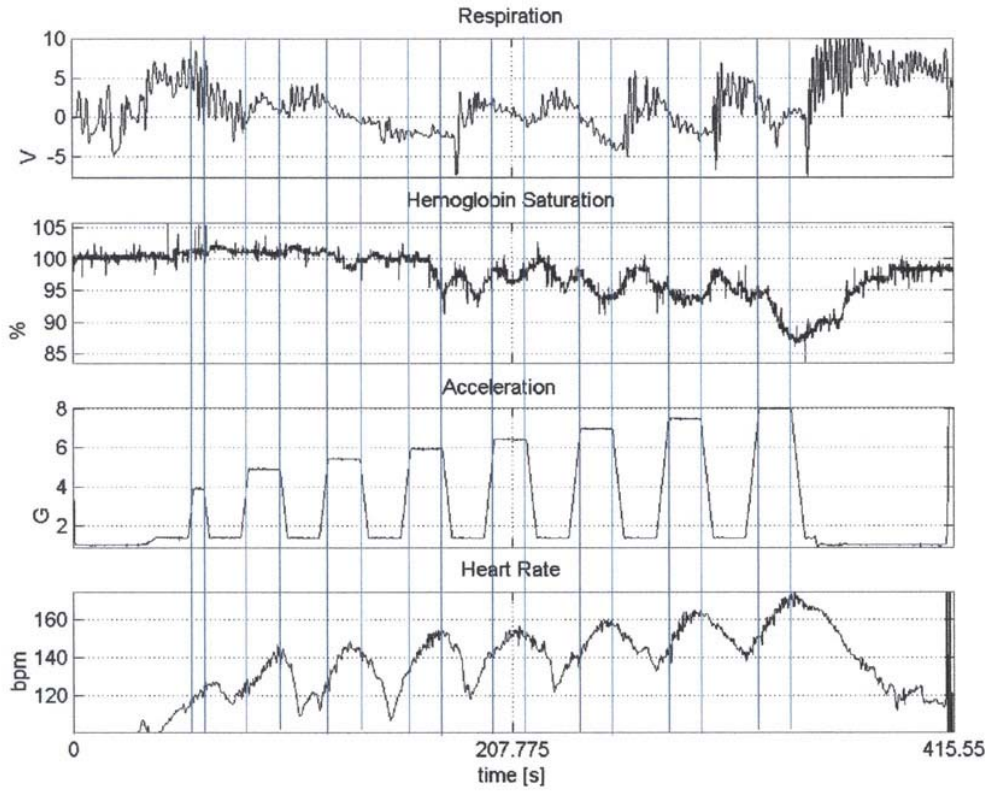


Fig. 16 Results of Subject 2 during ROR profile

In the exhalation phase, under G offset and in between intervals when the L-1 maneuver was not performed, HR was distinctively slowing. Results

from the last interval (F16) were respectively: HR- 162.1; %SO_2 - 86 a GTP – 8.1 G. According to the results of previous mandatory evaluations from years 2000 (7.8 G GOR) and 2002 (7.0 G ROR) (no anti-G suit), 52's results achieved with the anti-G suit and while performing the L-1 maneuver seem to be underrated and perhaps caused by a lack of training in the L-1 maneuver.

II examination

During this examination, subject 2 performed two intervals reaching on average 7.48 G and 8.57 G. (Fig. 17)

Zięć 4

	F01	F02	F03	F04	F05
Gz	1.38	7.48	5.40	8.57	1.01
SD	0.28	1.39	1.06	0.61	0.02
HR	112.42	149.40	166.05	173.01	146.13
SD	7.78	8.44	2.29	3.89	17.95

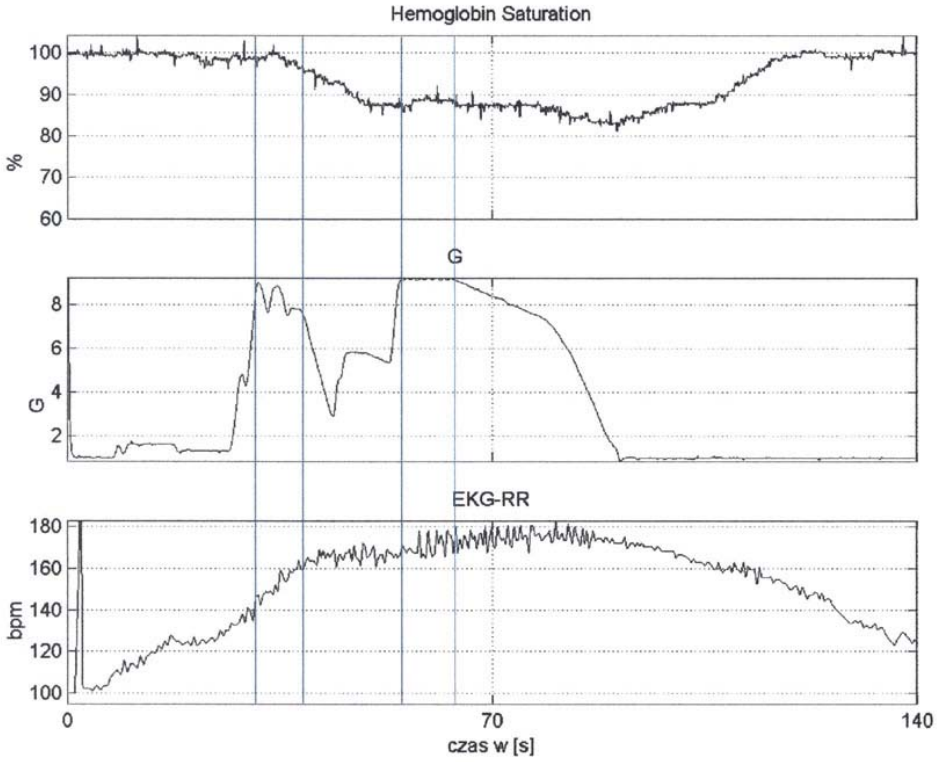


Fig. 17 Results of second examination of Subject 2 when reaching maximum G –

The second interval lasted for 12 seconds. During this profile the decrease in oxygen hemoglobin saturation was proportional to the examination time. His increase in HR was proportional as well. HR did not decrease between intervals. The average value of HR in the last interval was 173 bpm.

Subject 3

Libelle suit examination

Results of subject 3's examination are showed in Fig. 18

Brandis 3

	F01	F02	F03	F04	F05	F06	F07
Gz	1.08	4.96	2.44	6.46	3.31	9.10	1.02
SD	0.05	0.02	1.06	0.34	1.21	0.01	0.02
HR	102.25	125.00	118.50	136.09	137.06	148.13	120.52
SD	5.43	6.91	9.61	10.01	7.31	7.73	10.37

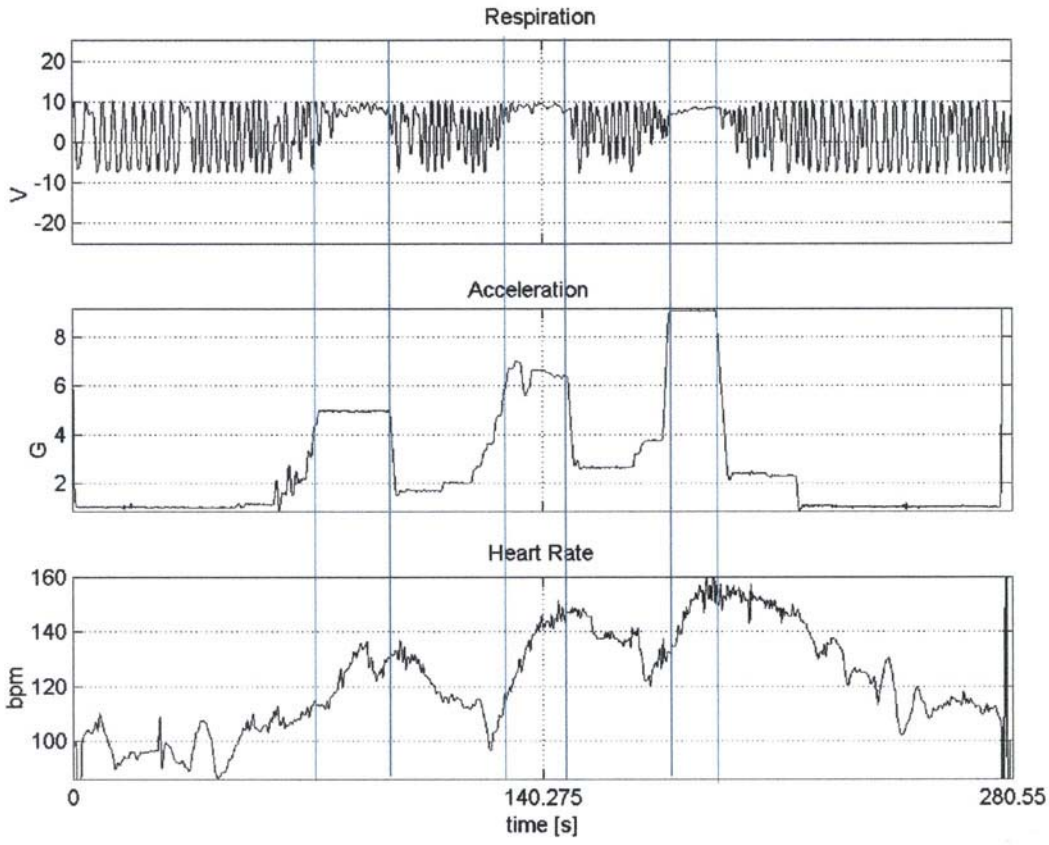
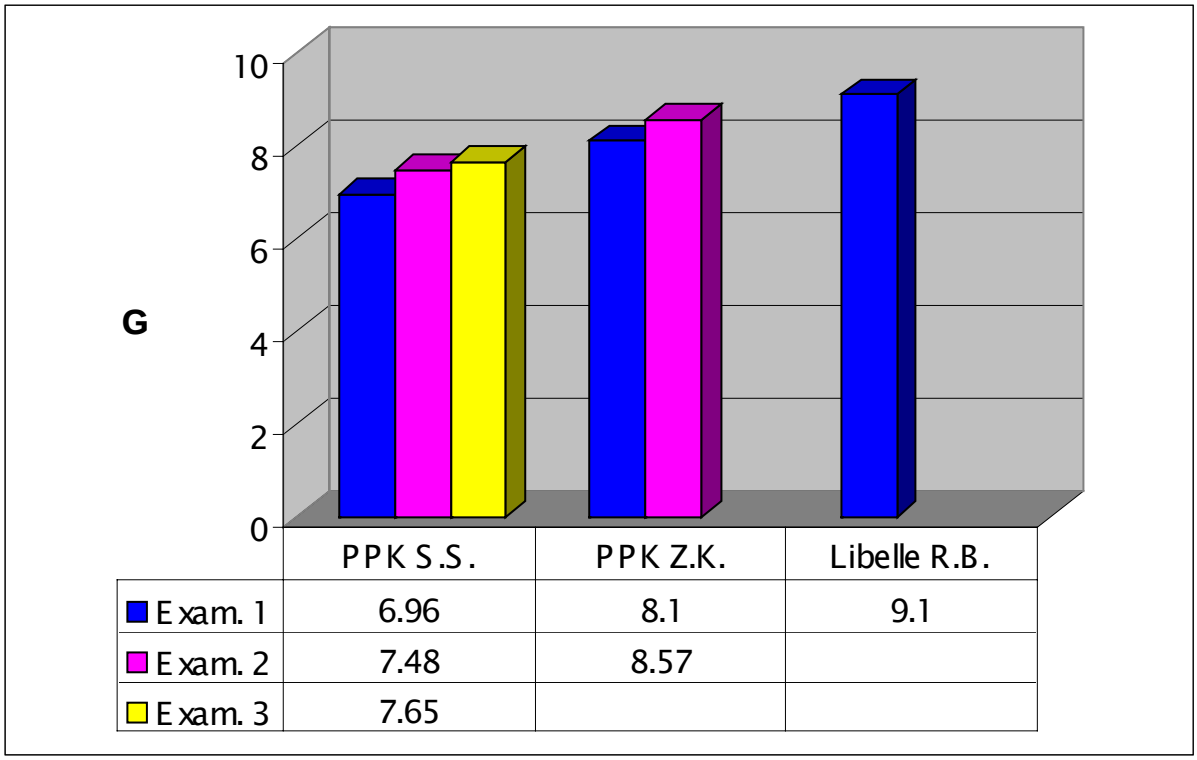


Fig. 18 Examination of Libelle suite with Libelle Straining Maneuver –

During this examination subject 3 performed three intervals with average acceleration values of 4.96 G, 6.46 G & 9.1 G. In all exposure, he seemed quite relaxed. During the last interval he waved with his left hand to the camera. In all of the intervals he kept vocal contact with the investigators, which could explain small disturbances in the HR recording observed in phase F03. In analyzing the breathing pattern it can be noticed that subject 3 was taking shallow, rather than



	PPK S.S.	PPK Z.K.	Libelle R.B.
Exam. 1	6.96	8.1	9.1
Exam. 2	7.48	8.57	
Exam. 3	7.65		

deep, breaths at peak G. This breathing technique appeared to work for the subject who maintained clear vision throughout. Average HR during the last two intervals was 137.2 and 147.2 bpm respectively. Despite reaching 9G, the decrease in percent oxygen hemoglobin saturation was minimal and between the second and third interval was 90%, and the last interval reached 97%. After the examination, subject 3 did not show signs of fatigue.

Fig. 19 shows maximum G values reached by subjects 1 and 2 using PPK A-G suit and by subject 3 using the Libelle A-G suit. They are presented as a bars grouped for each subject.

Fig. 19 Comparison of the results for the PPK and Libelle suits

To achieve maximum value of acceleration protection, subjects using the PPG repeated the profile (subject 1 three times and subject 2 two times). The comparative analysis shows that despite the PPK A-G suit protection and performance of L-1 maneuver respective results were lower than those obtained for subject 3 using the Libelle A-G suit.

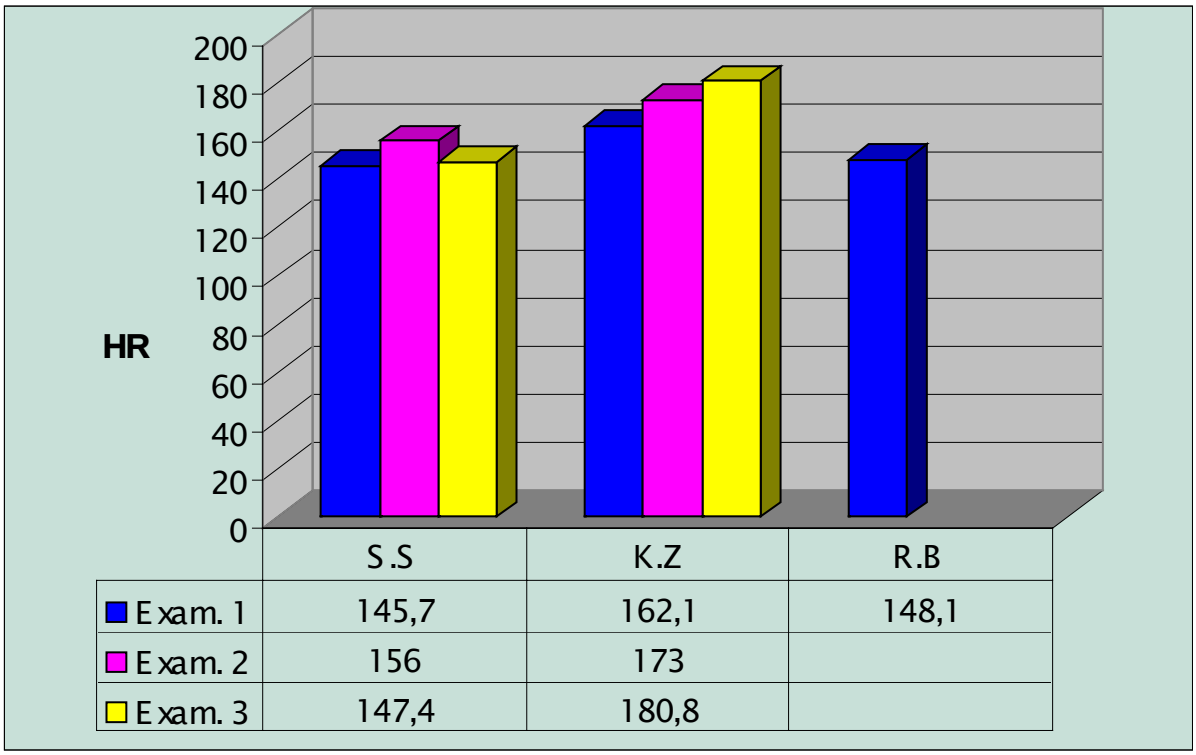


Fig. 20 Comparison of HR results during maximum acceleration -

Fig 20 shows that much higher HR results were present in subjects using the PPK. It suggests lower workload for the cardiovascular system for the subject using the Libelle A-G suit.

DISCUSSION

CONCLUSIONS

Results connected with I stage of examination

1. Use of A-G suit capstan type (WUK), in comparison to A-G suit with bladders increases ATL by 0.3 G.
2. Use of WUK suit allows more stabilization in cardiovascular parameters in comparison to PPK suit (with bladders) .
3. Introduction the profile called Condensed Intervals and indices of computerized analysis of visual-motor reaction and ear lobe pulsation allowed for objective assessment of ATL while maximum workload was decreased.
4. Increase of ATL with WUK suit on average by 1.4 G and with PPK suit by 1.1 G, as compared to the baseline might be underrated due to very strenuous interval profile performed in a short time.
5. Individual subjective comparative assessment of both types of suits for their efficiency under high acceleration is advantageous for capstan type suit.

Results of II stage examination

1. Determining the differences between Polish PPK A-G suits with water augmented Libelle suit, showed better ATL tolerance in Libelle.
2. Much higher HR values while ATL, present in Subjects using PPK A-G suits as compared with Subject using Libelle A-G suit shows higher workload for cardiovascular system while using PPK suit.
3. Analysis of HR return to the baseline values showed that it happened faster for the Subject using Libelle A-G suit, which shows less fatigue during examination.
4. Obtaining objective comparative results will be possible after examining the same subjects with WUK, PPK, and Libelle.

Presented results are difficult to compare because there was no possibility to perform examinations of the same subjects with different A-G suits. Study with full G protection provided by the WUK and PPK A-G suits with performance of the L- maneuver allowed us to assess the maximum efficiency of those systems. Acquired results show the possibilities in pilot protection against sustained G.

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